High Concentrations of Heavy Metals in Neighborhoods Near Ore Smelters in Northern Mexico

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In developing countries, rapid industrialization without environmental controls has resulted in heavy metal contamination of communities. We hypothesized that residential neighborhoods located near ore industries in three northern Mexican cities would be heavily polluted with multiple contaminants (arsenic, cadmium, and lead) and that these sites would be point sources for the heavy metals. To evaluate these hypotheses, we obtained samples of roadside surface dust from residential neighborhoods within 2 m of metal smelters [Torreón (n = 19)] and Chihuahua (n = 19)] and a metal refinery [Monterrey (n = 23)]. Heavy metal concentrations in dust were mapped with respect to distance from the industrial sites. Correlation between dust metal concentration and distance was estimated with least-squares regression using log-transformed data. Median dust arsenic, cadmium, and lead concentrations were 32, 10, and 277 µg/g, respectively, in Chihuahua; 42, 2, and 467 µg/g, respectively, in Monterrey, and 113, 112, and 2,448 µg/g, respectively, in Torreón. Dust concentrations of all heavy metals were significantly higher around the active smelter in Torreón, where more than 90% of samples exceeded Superfund cleanup goals. At all sites, dust concentrations were inversely related to distance from the industrial source, implicating these industries as the likely source of the contamination. We concluded that residential neighborhoods around metal smelting and refining sites in these three cities are contaminated by heavy metals at concentrations likely to pose a health threat to people living nearby. Evaluations of human exposure near these sites should be conducted. Because multiple heavy metal pollutants may exist near smelter sites, researchers should avoid attributing toxicity to one heavy metal unless others have been measured and shown not to coexist. *Key words:* arsenic, cadmium, industrial pollution, lead, metal smelter, Mexico. *Environ Health Perspect* 107:279–284 (1999). [Online 10 March 1999]
http://ehpnet1.niehs.nih.gov/docs/1999/107p279-284benin/abstract.html

The growth of industry in northern Mexico has created the potential for environmental problems; unfortunately, attention to environmental controls has lagged behind the pace of industrialization (*1–12*). Industrial sites such as ore smelters are often located in residential areas, where they possibly expose adults and children to heavy metals through inhalation and ingestion of contaminated soil and dust. Heavy metal contamination of dust is especially problematic for children who through hand-to-mouth activity may ingest as much as 90 mg of soil per day (*13–15*).

Previous studies of heavy metal exposure in Mexico focused primarily on lead in gasoline and household ceramics. Other environmental contaminants such as cadmium and arsenic have been largely ignored. Likewise, there is little investigation of industrial pollution from smelters and refineries (*1,2,6,8,16*). In other countries, lead, arsenic, and cadmium have been established as health threats to people living in communities surrounding ore smelters and refineries (*17–20*).

With the knowledge that ore smelters and refineries are potential sources of environmental heavy metal contamination, we hypothesized that there would be arsenic, cadmium, and lead in residential areas surrounding three industrial sites in northern Mexico. To evaluate this hypothesis, we collected roadside dust samples and analyzed them for the three heavy metals.

Materials and Methods

Study areas. Roadside dust samples were collected in July 1995 from the cities of Torreón, Monterrey, and Chihuahua. The primary factors in forming the sampling plan were location within a residential neighborhood and within 2,500 m of the industrial site. These northern Mexican cities have dry and dusty arid to semiarid climates with annual rainfall of less than 10–20 inches (*21,22*). In all three cities, residential areas lack any substantial ground cover such as grass or bushes because of the arid climate. In Chihuahua and Torreón most of the roads in residential areas were unpaved. The industrial sites in all cities were similar in that residential neighborhoods were sited immediately adjacent to the boundaries of the complex.

Torreón is a manufacturing and mining center with a population of approximately 500,000 people (*23*). The largest nonferrous metallurgical complex in Latin America (Industrias Peñoles S.A. de C.V.) and the fourth largest in the world is situated in Torreón. This smelter site, built in the early part of this century, processes approximately one-third of the lead ore in Latin America (*2*) and in 1996 produced 166,000 metric tons of lead and 123,000 metric tons of zinc (*24*). This industrial complex also contains a lead–silver foundry and a zinc plant. As shown in Figure 1, the smelter complex is surrounded on three sides by residential neighborhoods, from which roadside dust samples were collected.

Chihuahua, Mexico (population 400,000), has historically been a prosperous mining center (*25*). Chihuahua has a smelter complex (Mexico Desarollo Industrial Minero S.A.) (*26*), which had been inactive for approximately 5 years at the time of sampling. Nineteen samples were collected in residential areas immediately south of the Chihuahua smelter, some of which were originally built for smelter employees.

Monterrey is a commercial capital in northern Mexico. It is a city of 3 million people with a large industrial base (*5*). Twenty-three samples were taken from the residential neighborhoods around an active lead crystal factory and an inactive lead refinery (Mexico Desarollo Industrial Minero S.A.). Refining is a step beyond smelting in the ore purification process.

Sample collection. The environmental dust samples were collected at the edges of residential streets with a portable Dust Buster (Black & Decker, Latham, NY) using a sampling method similar to that used by Kimbrough et al. (*27*). Between each sample, the filter was changed and the interior of the vacuum was brushed with a small brush and wiped with a moist towellette. We selected sampling sites in the densely populated areas within a 2-m radius of the industrial site.

Analytic methodology. Measurement of dust heavy metal concentrations was performed at the Kettering Laboratory at the University of Cincinnati, Cincinnati, Ohio.

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This study was supported by an American Academy of Pediatrics resident research grant and a Helen's Fund grant from the Department of Pediatrics, Dartmouth–Hitchcock Medical Center.

Received 31 August 1998; accepted 29 December 1998.

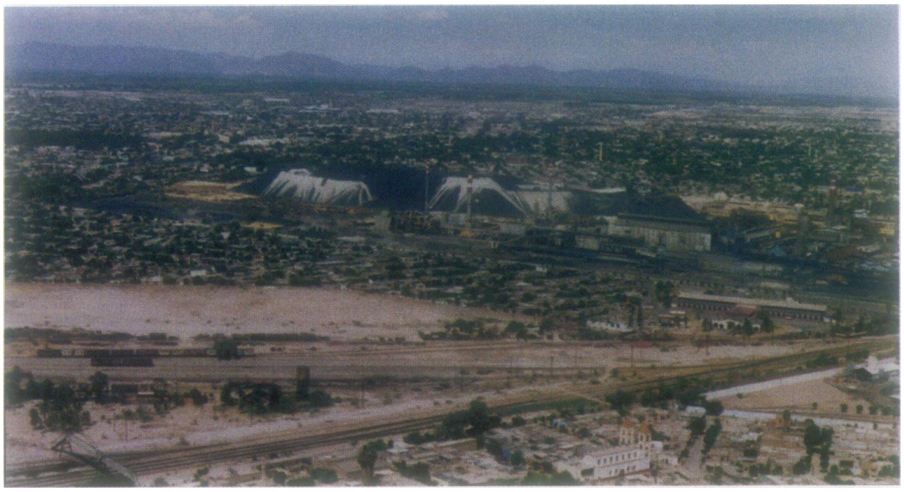
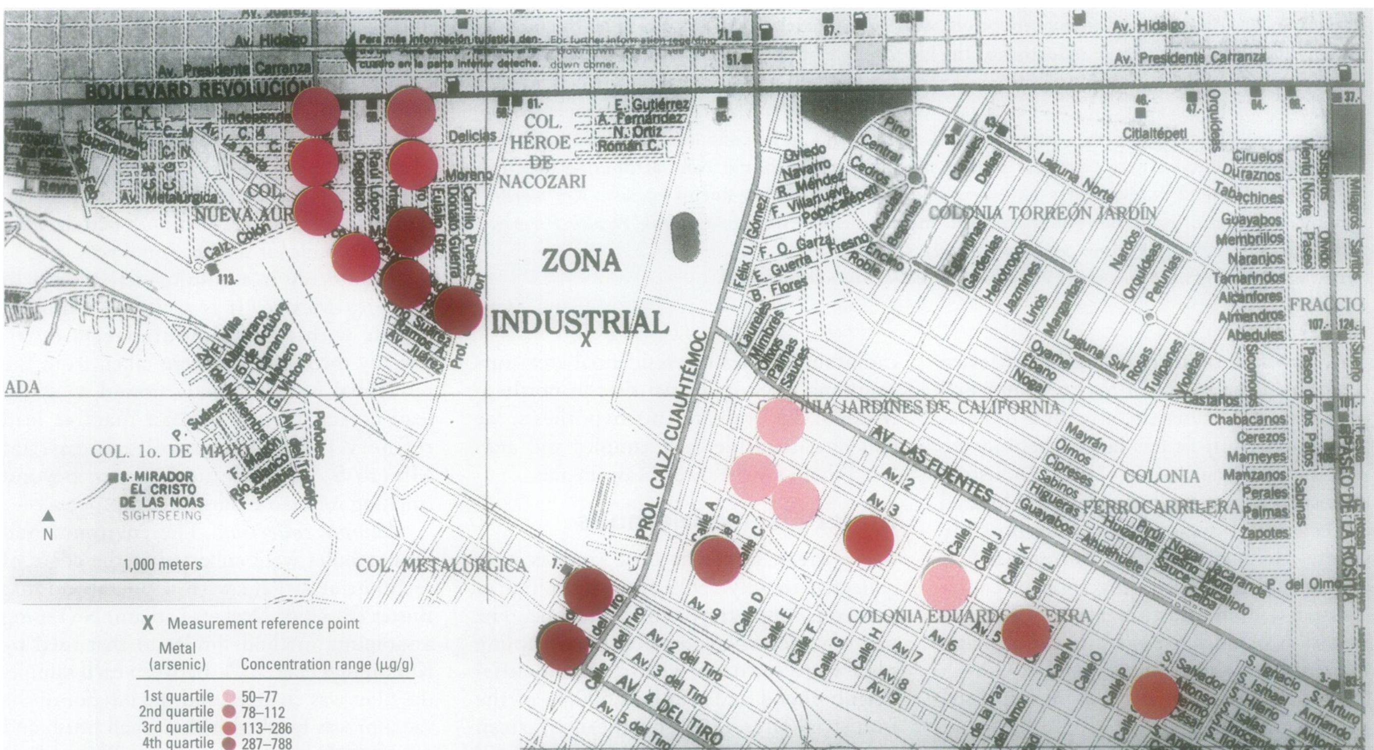


Figure 1. Aerial photograph of the Met–Mex Peñoles smelter with surrounding residential neighborhoods in Torreón, Mexico.

The Kettering Laboratory is a reference laboratory for the Centers for Disease Control and Prevention and participates in accreditation programs under the American Industrial Hygiene Association, the National Lead Laboratory Accreditation Program, The Environmental Lead Proficiency Analytical Testing Program, and the New York Environmental Laboratory Accreditation Program. The samples were prepared by drying, homogenizing, and sieving, retaining only particles <250 microns. The dust samples were then digested using 1 M nitric acid (National Institute for Occupational Safety and Health method 7082) (*28*) and this solution was filtered and analyzed for lead content by atomic absorption spectroscopy. Using these methods during the period of analysis, we achieved a 98 ± standard deviation of 4.8% recovery for arsenic, a 94 ± 2.5% recovery for cadmium,



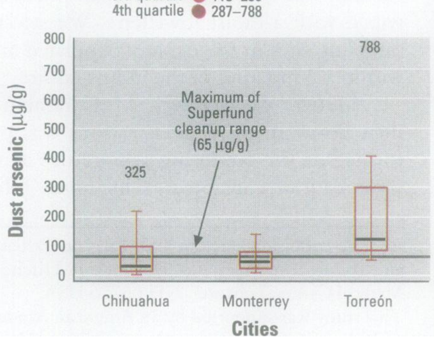


Figure 3. Map of arsenic concentrations in residential roadside dust near the Met–Mex Peñoles smelter complex in Torreón, Mexico. The smelter complex is the Zona Industrial area. The four color shades correspond to the four quartiles of dust arsenic, in micrograms per gram. Distance was measured from a measurement reference point, approximately the emissions stack.

Figure 2. Boxplot graphs for residential roadside dust arsenic concentration near ore industry sites in three northern Mexican cities. The outer bounds of the boxes represent the interquartile range; the median is represented by the midline. The whiskers represent the adjacent values, with the high adjacent value being the last case not more than 1.5 times the interquartile range beyond the 75th percentile. Data points (in micrograms per gram) outside the high adjacent values are plotted and labeled above the whiskers.

and a 96 ± 2.5% recovery for lead. The coefficient of variation for arsenic was 8.3% at 25 µg/g and 1.4% for 140 µg/g; for cadmium, 7.5% at 1 µg/g and 6.7% at 80 µg/g; and for lead, 8% at 400 µg/g and 1.3% at 2,300 µg/g.

Data analysis. We calculated medians and interquartile ranges (IQRs) for concentrations of each heavy metal at each of the three sites. These results were then compared by site and with reference to values established as acceptable by the EPA, using previously documented background soil levels and EPA cleanup goals for Superfund sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (*13*) for comparison. Background soil arsenic is 1–50 µg/g, and soil arsenic >100 µg/g correlates with biological toxicity (*13,29,30*). Superfund soil arsenic cleanup goals are 5–65 µg/g (*13*). Natural background levels of soil cadmium are 0.01–0.7 µg/g, and urban values range from <0.01 to 8.0 µg/g; Superfund cleanup goals are 3–20 µg/g (*13,29*). Lead concentration of >250 µg/g in urban dust or soil has been defined as hazardous to humans (*31*). Background levels range from 2 to 200 µg/g in soil. EPA cleanup goals for Superfund sites under CERCLA are 200–500 µg/g lead in soil (*13*).

Metal concentrations for each sampling location were mapped to a street map of the industrial sites and their surrounding neighborhoods. The approximate location of the emissions stack of each industrial complex was chosen as a reference point from which to measure distance to each of the sampling locations. Thus, samples at the perimeters of the complex sites have varying distances from the reference point, beginning at approximately 400 m from the Torreón and Chihuahua complexes and 200 m from the Monterrey refinery. To confirm that the industrial complex was the probable point source, we regressed the natural logarithm (ln) of metal concentration against ln distance (in meters) from the industrial site using least-squares regression and report p-values and R^2 values for these models. Finally, comparisons of log dust metal concentrations were made by city using regression with dummy variables (*32*).

Results

In all three cities heavy metal concentrations exceeded levels considered background and also exceeded maximum acceptable levels by the EPA for cleanup at Superfund sites under CERCLA (*13*).

Arsenic. Figure 2 uses box plots to illustrate the distribution of residential roadside dust arsenic for the three sites. In Chihuahua the median dust arsenic concentration was

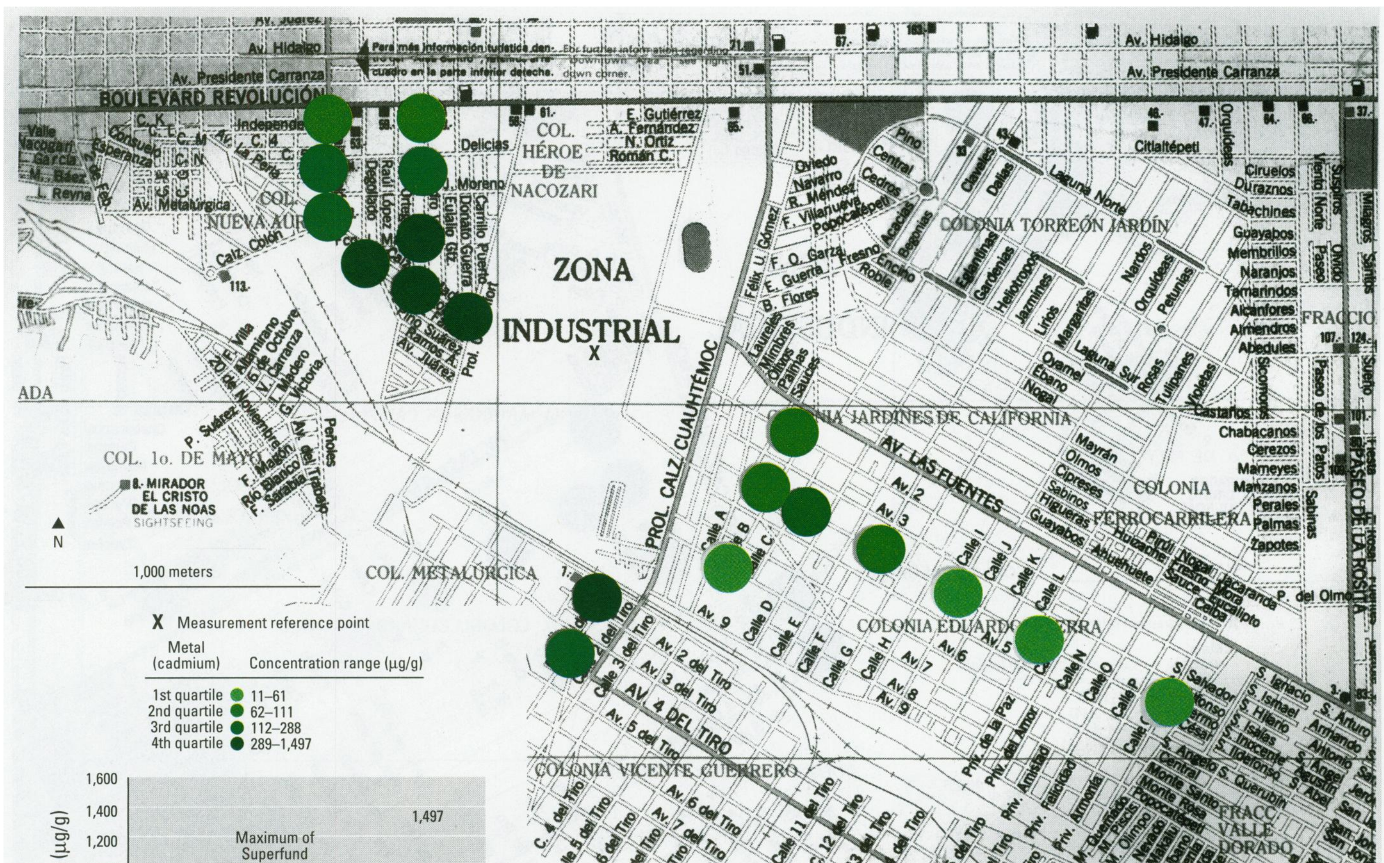


Figure 5. Map of cadmium concentrations in residential roadside dust near the Met–Mex Peñoles smelter complex in Torreón, Mexico. The smelter complex is the Zona Industrial area. The four color shades correspond to the four quartiles of dust cadmium, in micrograms per gram. Distance was measured from a measurement reference point, approximately the emissions stack.

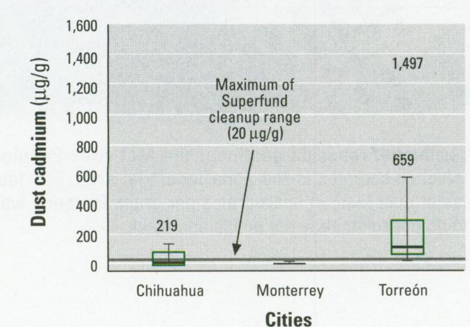


Figure 4. Boxplot graphs for residential roadside dust cadmium concentration near ore industry sites in three northern Mexican cities. The outer bounds of the boxes represent the interquartile range; the median is represented by the midline. The whiskers represent the adjacent values, with the high adjacent value being the last case not more than 1.5 times the interquartile range beyond the 75th percentile. Data points (in micrograms per gram) outside the high adjacent values are plotted and labeled above the whiskers.

32 μg/g (IQR 14–96 μg/g) with a 95th percentile of 325 μg/g. In Monterrey the median was 42 μg/g (IQR 17–73 μg/g) with a 95th percentile of 108 μg/g. In Torreón the median was 113 μg/g (IQR 78–287 μg/g) with a 95th percentile of 788 μg/g. Thirty-seven percent of the samples in Chihuahua, 35% of the samples in Monterrey, and 89% of the samples in Torreón exceeded the maximum Superfund cleanup goals for arsenic in dust. Dust arsenic levels were inversely associated with distance from the industrial sites and decreased exponentially as distance increased (Chihuahua R^2 = 0.38, p = 0.004; Monterrey R^2 = 0.35, p = 0.003; Torreón R^2 = 0.3, p = 0.01). Figure 3 shows a map of dust arsenic concentration around the Torreón site.

Cadmium. Figure 4 illustrates the distribution of residential roadside dust cadmium for the three sites. In Chihuahua the median dust cadmium concentration was 10 μg/g (IQR 3–70 μg/g) with a 95th percentile of 219 μg/g; in Monterrey the median was 2 μg/g (IQR 1–3 μg/g) with a 95th percentile of 5 μg/g; and in Torreón the median was 112 μg/g (IQR 62–289 μg/g) with a 95th percentile of 1,497 μg/g. Forty-two percent of the samples in Chihuahua, none of the samples in Monterrey, and 95% of the samples in Torreón exceeded the maximum Superfund cleanup goals for cadmium in dust. In Chihuahua and Torreón, dust cadmium levels were inversely associated with distance from the industrial complex center and decreased exponentially with increased distance (Chihuahua R^2 = 0.36, p = 0.007; Torreón R^2 = 0.7, p<0.0001). Figure 5 shows a map of dust cadmium concentration around the Torreón site.

Lead. Figure 6 illustrates the distribution of residential roadside dust lead for the three sites. The median dust lead concentration surrounding the inactive smelter in Chihuahua was 277 μg/g (IQR 201–1,654 μg/g) with a 95th percentile of 5,453 μg/g. In Monterrey the median lead concentration was 467 μg/g (IQR 309–554 μg/g) with a 95th percentile of 783 μg/g. Dust samples in Torreón had median lead concentration of 2,448 μg/g (IQR: 179–4,884 μg/g) with a 95th percentile of 13,231 μg/g. Forty-two percent of the samples in Chihuahua, 39% of the samples in Monterrey, and 100% of the samples in Torreón exceeded the maximum Superfund cleanup goals for lead in dust. As seen in Figures 3 and 5, concentrations for samples taken closest to the Torreón smelter are highest to the south and west. Dust lead levels were inversely correlated with distance from the industrial sites in Chihuahua and Torreón (Chihuahua R^2 = 0.4, p = 0.003;

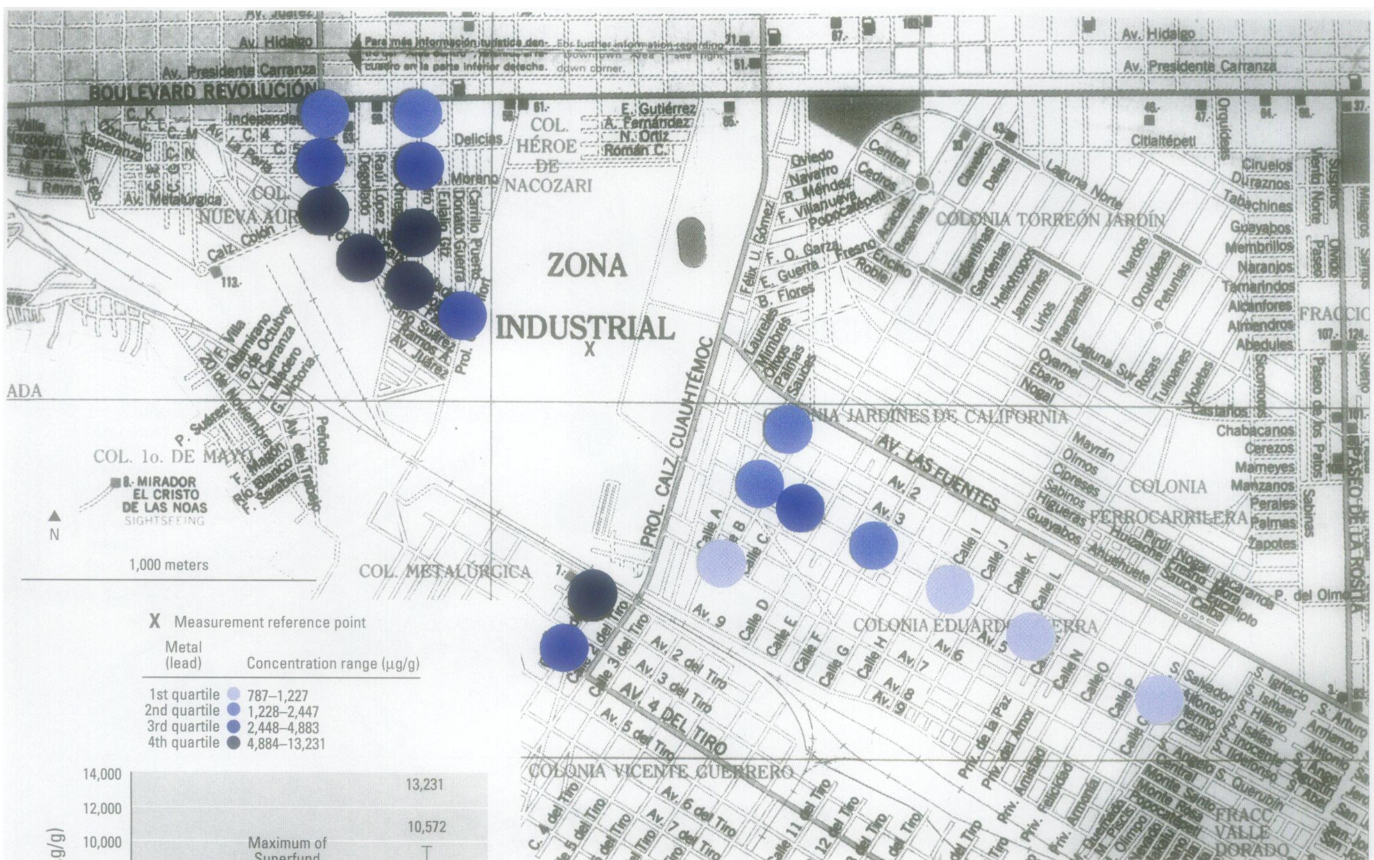


Figure 7. Map of lead concentrations in residential roadside dust near the Met–Mex Peñoles smelter complex in Torreón, Mexico. The smelter complex is the Zona Industrial area. The four color shades correspond to the four quartiles of dust lead, in micrograms per gram. Distance was measured from a measurement reference point, approximately the emissions stack.

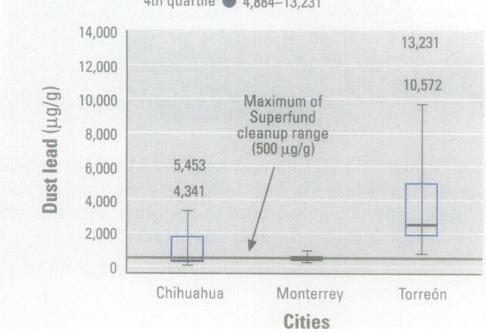


Figure 6. Boxplot graphs for residential roadside dust lead concentration near ore industry sites in three northern Mexican cities. The outer bounds of the boxes represent the interquartile range; the median is represented by the midline. The whiskers represent the adjacent values, with the high adjacent value being the last case not more than 1.5 times the interquartile range beyond the 75th percentile. Data points (in micrograms per gram) outside the high adjacent values are plotted and labeled above the whiskers.

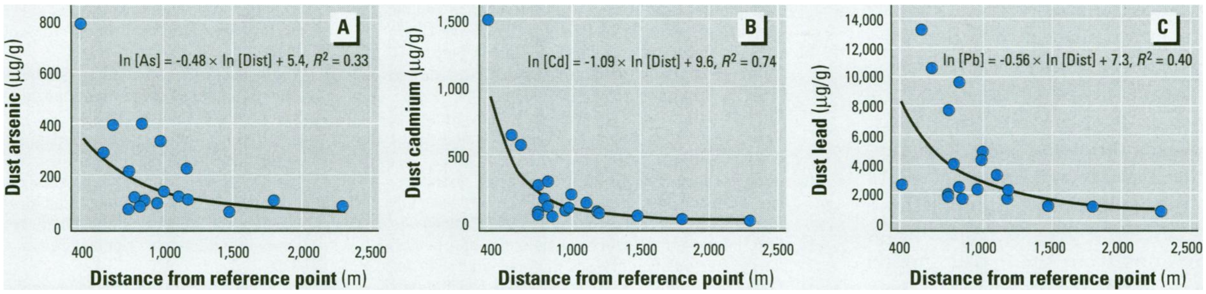


Figure 8. Plots of dust heavy metal concentration versus distance from the reference point, approximately the emissions stack of the industrial complex in Torreón, Mexico. (A) Arsenic; (B) cadmium; and (C) lead.

Torreón R^2 = 0.4, p = 0.004). Figure 7 shows a map of dust lead concentration around the Torreón site (*33*).

Plots of the dust concentration of arsenic, cadmium, and lead versus distance from the emissions stack at the industrial site in Torreón are shown in Figure 8, illustrating the exponential decline in concentration as distance from the site increases. To test whether heavy metal concentrations were significantly higher to the south and west of the site, a dummy variable (1 for dust samples taken from the east, 0 for all others) was included with controls for distance. In models for all three heavy metals, those samples taken from the eastern side contained significantly lower concentrations. This could reflect the effect of prevailing winds, which come out of the northeast (*34*), or other factors such as transportation, unloading, and distribution of ore within the complex.

Comparison by city. Using Monterrey as a reference, concentrations of all heavy metals were significantly higher in Torreón (Table 1). Only cadmium concentrations were significantly higher in Chihuahua as compared to Monterrey.

Discussion

With the exception of cadmium in Monterrey, the level of heavy metal pollution exceeds Superfund cleanup goals in all three cities. In Chihuahua and Torreón level of contamination for all three metals is inversely related to distance from the industrial site, implicating the site as the source of the pollution. Moreover, contamination appears substantially and significantly higher for all metals around the active smelter as compared to the inactive smelter and metal refinery. Although we were not able to collect biological samples in this study, dust lead, arsenic, and cadmium have previously been correlated with blood and urine values in populations surrounding industrial sites; likewise, numerous studies have found an inverse relationship between blood and urine levels and distance of home or school environment from metal smelters (*17–19,35,36*).

The extent of the arsenic contamination is comparable to that found elsewhere around similar industries (*1,29,37–41*). In a review of the literature, the cadmium contamination around the active smelter in Torreón exceeds any previously reported level of contamination (*1,29,42,43*), with most samples exceeding the Superfund site clean-up goals of 20 µg/g. In one of the few published studies in Mexico, Díaz-Barriga et al. (*1*) documented the biological significance of high environmental cadmium concentrations around a zinc smelter in San Luis Potosí, Mexico. In that study, median dust cadmium of 42 µg/g (range 29–214 µg/g) corresponded to urinary cadmium mean of 1.04 µg/g creatinine (range 0.25–20 µg/g creatinine) in their sample of children aged 3–6 years. Industrial standard safety thresholds for adult workers in the cadmium industry are 5–10 µg/dl blood or 5–10 µg/g creatinine in urine, and cadmium workers have reported blood cadmium ranging from 0.6 to 164 µg/l (*42,44*). Based on this background and given the roadside dust levels in Torreón (12–1,497 µg/g), we expected body burdens in the residing population to be equivalent to that found in San Luis Potosí, and possibly much higher. A study of cadmium toxicity in Torreón smelter workers and residents surrounding the complex is urgently needed.

The dust lead levels are consistent with levels found in other studies of dusts and soils surrounding smelters; likewise, previous studies have shown inverse association with distance from the industrial source similar to the association in the present study (*18,36,45*). Based on prior studies of biological correlation of dust and soil lead (*18,20*), we predict that children living within 1 m of the Torreón complex will have average blood lead levels of ≥40 µg/dl. We predict blood lead levels of ≥20 µg/dl for children residing within 1 m of the complexes in Chihuahua and Monterrey (*16,17,19,20,27,45,46*). Blood lead levels in children at all three sites are likely to be well above the 10 µg/dl threshold of concern for lead in children set by the Centers for Disease Control and Prevention (*47*).

Table 1. Comparison among cities of residential roadside dust heavy metal concentrations

Dependent variable	Coefficient	*p*-Value
Ln (arsenic)		
Monterrey	Reference	
Chihuahua	0.09	0.36
Torreón	0.69	<0.0001
Ln (cadmium)		
Monterrey	Reference	
Chihuahua	0.83	<0.0001
Torreón	1.91	<0.0001
Ln (lead)		
Monterrey	Reference	
Chihuahua	0.07	0.53
Torreón	0.90	<0.0001

Ln, natural logarithm. Comparison made using multiple regression analysis with Ln (metal) as the dependent variable and dichotomous (dummy) variables for the city. All three regression models control for ln (distance) from the hypothesized source.

Finally, our data indicate that ore smelters are associated with environmental contamination involving multiple heavy metals. Studies that evaluate the association of only one of these heavy metals with health outcomes in children or adults living around smelter sites (*16–19*) may falsely implicate individual contaminants by failing to control for the confounding effects of other unmeasured heavy metals with overlapping toxicity profiles.

The industrial contamination documented in this study suggests that emissions from these Mexican-based industries are not well contained. Because smelting and refining processes release large quantities of heavy metals, the location of the industries near residential populations could expose many children and adults. Our study suggests that contamination in these areas, especially in Torreón, is sufficient to pose a hazard to the human population.

This study is limited by the small number of soil samples gathered at each site and by our inability to conduct human exposure measurements. In addition, we did not obtain dust samples from sites distant from the plant to evaluate the natural or background urban levels of these heavy metals in dust in each city. Further studies are necessary to determine the full extent of the industrial contamination and its impact on the resident population. The next logical steps in the investigation of these sites are 1) to obtain further air, dust, and soil measurements; 2) to measure particle size and heavy metal speciation (*48*); 3) to measure biological uptake and impact of multiple heavy metals in the local populations; and 4) to develop a plan to reduce heavy metal emissions from the active smelter and human exposure at all three sites. Preliminary studies have begun around the Torreón industrial complex in conjunction with persons from the Mexican government, industry, medical personnel at the medical school in Torreón, and an industrial emissions expert from the United States (*34*).

Conclusions

Dust arsenic, cadmium, and lead concentrations in residential neighborhoods surrounding metal smelters and refineries in three northern Mexican cities exceed safe ranges established by the EPA. In the majority of cases, the concentration of the heavy metal in dust samples declines exponentially as distance from the industrial site increases, implicating the industries as the probable source of the pollution. Further investigation into the extent of human exposure to all three heavy metals is urgently needed in Torreón.

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